

# Fabrication of tunnelling gap of nanomechanical accelerometer by focused ion beam

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**Abstract.** The two-layer polysilicon surface micromachining process flow of nanomechanical accelerometer included a high aspect-ratio etch step was presented. In the experiments we defined modes, and developed the technology of tunnelling gap formation using focused ion beam. The nanomechanical accelerometer crystals were fabricated by surface micromachining and focused ion beams.

## 1. Introduction

Many micromechanical gyroscopes and accelerometers were fabricated by bulk and surface micromachining [1-6]. Its process flows mainly based on optical lithography and dry/wet etching of substrate or sacrificial layer. Typically the substrate was silicon, polysilicon and silicon dioxide used as structural and sacrificial layers, respectively. The process flow of nanomechanical system could be also based on microelectronic IC technology and materials but need to be added special steps. For high-sensitivity accelerometers operating on tunnelling effect it could be a high aspect-ratio etch [1,7-9].

The tunnelling gap of nanomechanical accelerometer can be manufactured using Focused Ion Beam (FIB) technology [1,7-13]. FIB technology enables reproducible and precise material processing with high accuracy [14]. The key feature of FIB is the high spatial resolution which is provided by the application of a gallium ion beam 7 nm in diameter, as well as by the possibility of varying the impact of the parameters over wide limits [15]. In contrast to conventional fabrication techniques based on optical lithography with the application of photoresist and material processing a direct writing mode by FIB allows precise nanopatterning even on sample with advanced topography [16-19].

Focused ion beam allows creating nanosized structures and nanodevices with different shapes and parameters. Using the polycrystalline silicon allows minimizing the negative impact of the implanted gallium ions. Combination of FIB nanopatterning and FIB-induced local deposition of materials allows precise nanofabrication of tunnelling gaps with sub 5 nm width [20].

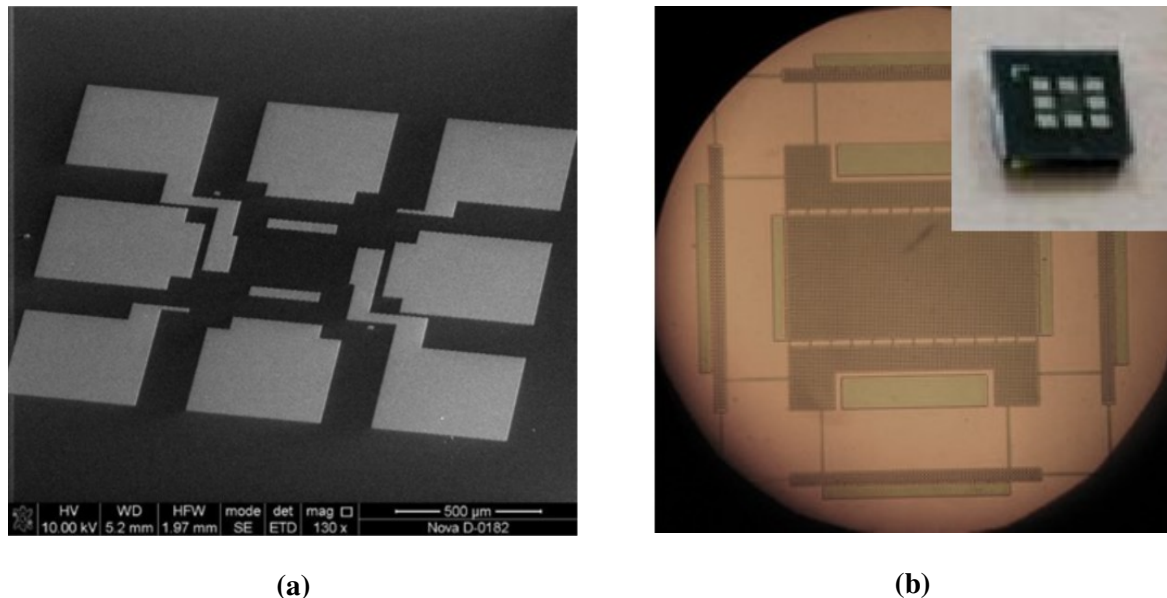
The objective of this work is the fabrication and study of tunnelling gap of nanomechanical accelerometer using the combination of FIB technology and atomic force microscopy measurements.



## 2. Formation of nanomechanical accelerometer samples for high aspect-ratio etch step

We propose integrated two-layer polysilicon surface micromachining process flow of micro- and nanomechanical gyroscope and accelerometers [21]. The process flow of nanomechanical accelerometer need to be include a high aspect-ratio etch step by focused ion beams.

We fabricate wafer of non-finished nanomechanical accelerometer for latest high aspect-ratio etch step (Figure 1) according following process flow. The substrate was 100 mm n-type silicon wafer Si (100). Insulator film of silicon nitride of 0.6  $\mu\text{m}$  thickness was grown on the substrate using inductively coupled plasma CVD (SemiTEq ICPd81). Than sandwich-like structures of bottom polycrystalline silicon, sacrificial silicon oxide and top polysilicon layers of 0.3, 1.5 and 2.0  $\mu\text{m}$  were prepared by plasma enhanced (Oxford Instruments PlasmaLab 100) and ICP CVD. The polycrystalline silicon films were doped using the liquid  $\text{PCl}_3$  diffusant (SD.OM-3M). Polysilicon inertial masses were fabricated by optical lithography (SUSS MJB4), dry etching under masks of photoresist, aluminum and nickel (SemiTEq ICPe68), and wet etching of sacrificial layer [21,22].



**Figure 1.** Optical image of first (a), second polysilicon layers and nanomechanical accelerometer crystal (b).

## 3. Fabrication of tunneling gap using focused ion beam

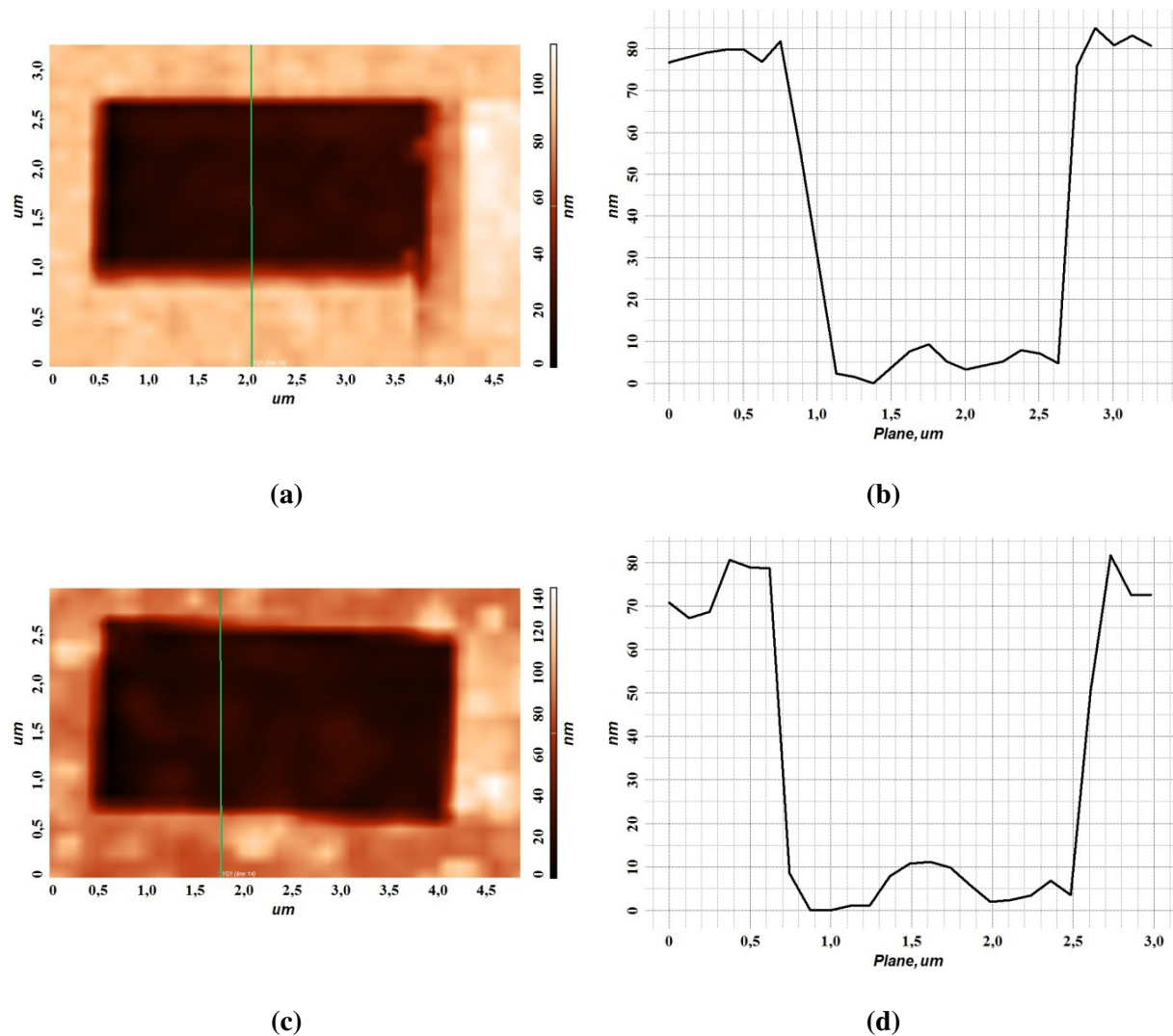
At the first step of our research we investigated the dependence between the ion milling depth and FIB current for doped and undoped polysilicon. The experimental study was carried out by the following procedure: an array of 4 by 2 micron squares was produced by FIB local milling on a polysilicon substrate at various ion-beam-treatment parameters: 1) FIB current  $I = 10, 30, 50, 100, 300$  nA; 2) Beam dwell time  $Dt = 50$  microsecond; 3) Total FIB milling time at square structure  $T = 60$  sec.; 4) FIB overlap  $OL = 50\%$ . The number of ion-beam passes (#) for a given graphic pattern was chosen so that the total time of FIB exposure at each structure is 1 minute for each value of the ion beam current.

The process of ion-beam etching was monitored by scanning electron microscopy. The morphology and geometric characteristics of the structures were analyzed using an Ntegra Vita scanning probe nanolaboratory in the intermittent mode of atomic force microscopy (Figure 2).

The results allow to calculate the dependence between FIB milling depth and ion beam current (Figure 3). The analysis of curves gives an indication of the ion-beam milling speed for different values of ion-

beam current. The values of the etching rates were identified during the research. It is found that the formation of tunneling gap must apply the minimum FIB current values (approx. 1-10 pA) that corresponds to the milling rate of about 10 nm/min.

The fabrication of tunneling gap was performed with a Unique scientific equipment “Electron beam microscope with electron lithography system” Nova Nanolab 600, combining a  $\text{Ga}^+$  FIB and a field emission scanning electron microscope [10].



**Figure 2 (a-d).** Profiling of substrate surface using focused ion beam. AFM-images and profiles of undoped(a,b) and doped (c,d) samples after FIB local milling.

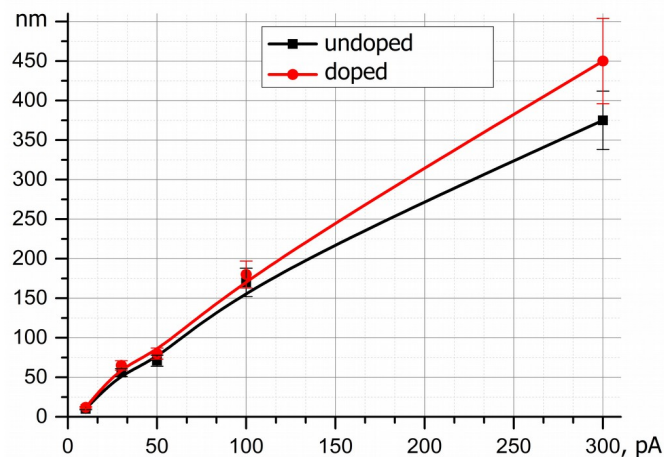
For the tunneling gap fabrication the following FIB parameters were used: the accelerating voltage of the ion beam – 30 keV; the ion beam current – 1.0 pA; and the dwell time of the ion beam - 1.0  $\mu\text{s}$ . Figure 4(a) shows the SEM image of FIB-fabricated tunnelling gap on polysilicon structure. The total width of the gap is approximately 22.0 nm which is not suitable for tunneling devices. To reduce the width of the gap the method of FIB-induced deposition of tungsten was used. After the ion-induced deposition, the gap width was reduced to approximately 4.0 nm as shown at Figure 4(b).

#### 4. Conclusion

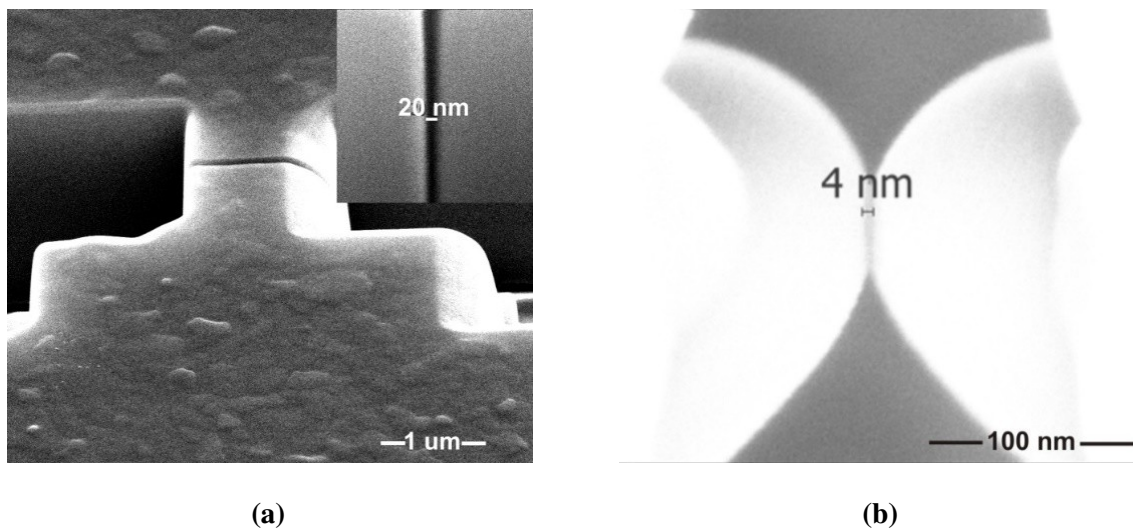
Previously we fabricate wafer of half-finished nanomechanical accelerometer by surface micromachining for latest high aspect-ratio etch step.

Then we have illustrated the procedure, based on FIB milling and deposition, to create of tunneling gap of nanomechanical accelerometer. It is shown that the use of FIB technology allows forming tunneling gaps with different values of the electrode spacing. It is shown that at minimum FIB current values the polysilicon milling rate is about 10 nm/min.

Finally the nanomechanical accelerometer with tunneling gap were finished by FIB.



**Figure 3.** FIB milling depth vs. ion beam current (exposure time of 1 minute).



**Figure 4 (a, b).** SEM image of nanoaccelerometer gap: etched (a) and deposited (b).

Combining scanning probe technology and bitmap-based FIB technology will open a new direction of development of MEMS and NEMS. The obtained results can be used to develop the technological processes of the production of nanomechanical accelerometers.

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